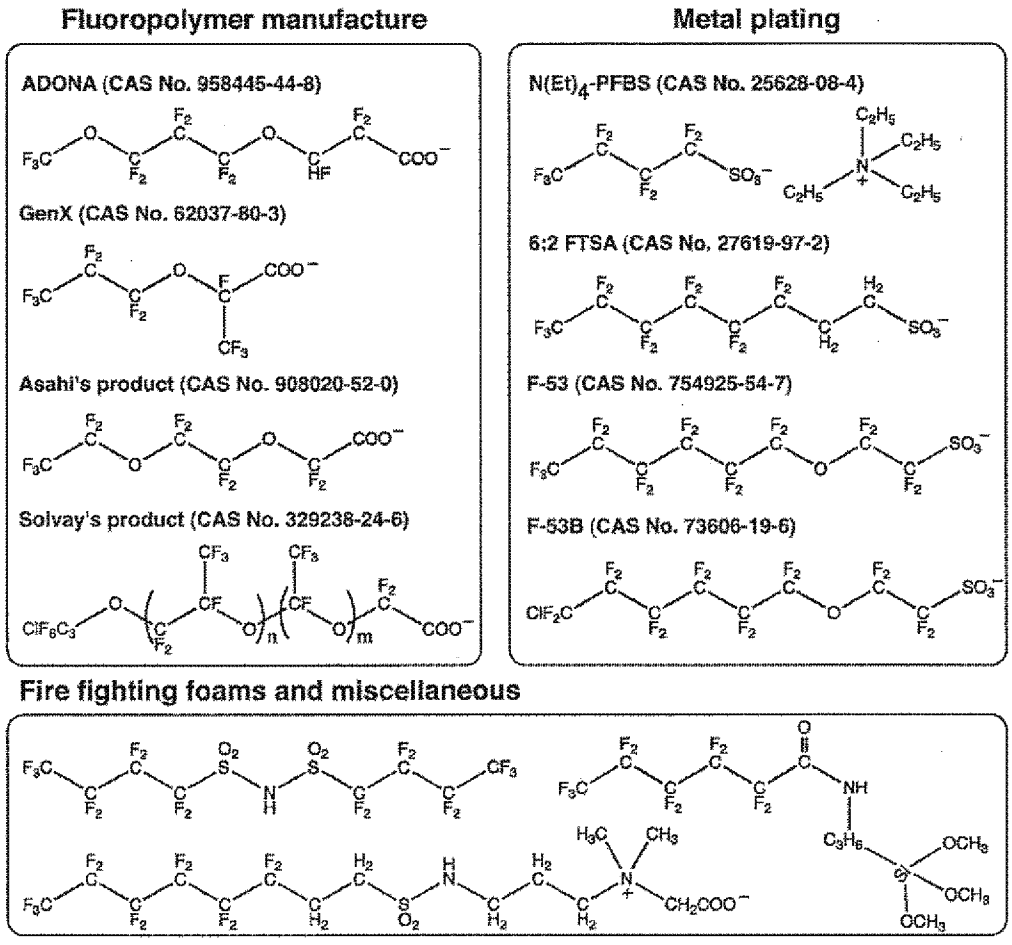

Fig. 1. Examples of fluorinated alternatives identified in different industry branches.

$(OCF_2)_p$-$\{OCF_2CF_2)_q$-OCF_2CH_2-$\{OCH_2CH_2)_n$-$OP(OH)(O)(OH)$ (Trier et al., 2011)) have been used as alternatives (Solvay, 2011).

2.4. Metal (chromium) plating

Historically, salts of PFOS have been used as wetting agents and mist-suppressing agents in decorative plating and non-decorative hard plating. Recent technology development using chromium-III instead of chromium-VI has made PFOS use in decorative chrome plating obsolete. Chromium-III, however, cannot be used for hard chrome plating (UNEP, 2012). In Europe, salts of 6:2 fluorotelomer sulfonic acid (6:2 FTSA, $C_6F_{13}C_2H_4SO_3H$) are applied as alternatives to PFOS, however, they can only partly be applied in decorative plating due to slightly higher surface tension compared to PFOS (UNEP, 2012). In addition, $N(Et)_4$-PFBS (CAS No. 25628-08-4) is registered for metal plating under REACH with a production volume of 1–10 tonnes per annum (ECHA, 2013b). Also, a German producer reported a production of 20–50 tonnes of PFBS-based $[C_4F_9SO_2N(CH_3)CH_2CH_2O]_2P(O)OH$ (CAS No. 120945-47-3) in 2003, which is used as defoamer in the electroplating industry (OECD, 2005). In China, several producers have used F-53 (salts of $C_6F_{13}OCF_2CF_2SO_3H$, CAS No. 754925-54-7) and F-53B ($Cl\text{-}C_6F_{12}OCF_2CF_2SO_3K$, CAS No. 73606-19-6), likely derived from fluorotelomer raw materials, since the late 1970s (Huang et al., 2010; UNEP, 2012). It is estimated that about 20–30 tonnes of F-53 and F-53B were used in 2009 in the metal plating industry (both decorative and hard metal plating) in China (Huang et al., 2010).

2.5. Fire-fighting foams

In the past, various PFCA-, PFSA-, and fluorotelomer-based derivatives were added (i) as film formers in aqueous film forming foams (AFFFs) and film forming fluoroproteins (FFFPs), (ii) as fuel repellents in fluoroprotein foams (FPs), and (iii) as foam stabilizers in FFFPs and alcohol-resistant aqueous film-forming foams (AR-AFFFs) (Backe et al., 2013; Kleiner and Jho, 2009; Place and Field, 2012). In 2002 3M, which was the only producer, ceased its global production of POSF-based AFFFs (Place and Field, 2012); and thereafter has developed a fire suppression agent based on a gaseous fluorinated ketone $[CF_3CF_2C(O)CF(CF_3)_2$, CAS No. 756-13-8] (UNEP, 2012). Also, AFFFs based on pure 6:2 fluorotelomers are under development to replace the early generations that are based on a mixture of predominantly 6:2 and 8:2 fluorotelomers (Klein, 2012; Kleiner and Jho, 2009). For example, DuPont commercialized Forafac® 1157 that is based on 6:2 fluorotelomer sulfonamide alkylbetaine [6:2 FTAB, $C_6F_{13}C_2H_4SO_2NHC_3H_6N^+(CH_3)_2CH_2COO^-$] (Hagenaars et al., 2011; Moe et al., 2012; Pabon and Corpart, 2002) and Forafac® 1183 that is based on 6:2 fluorotelomer sulfonamide aminoxide $[C_6F_{13}C_2H_4SO_2NHC_3H_6N(O)(CH_3)_2$, CAS No. 80475-32-7] (Jensen et al., 2008). In addition, a Chinese institute has developed an AFFF formulation based